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Reference no. 090

Title: Structural behaviour characterization of existing adobe constructions in Aveiro

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Abstract

Adobe was a widely used construction material in Aveiro, Portugal, till the middle of the 20th century. Nowadays, adobe can still be found in varied types of constructions, many of which are of cultural, historical, and also architectural recognized value.
The existing adobe buildings present an important level of structural damage and, in many cases, are even near to ruin, having the majority a high vulnerability to seismic actions. To face the lack of information concerning the mechanical properties and structural behaviour of adobe structures, it was developed an experimental campaign. The composition and mechanical behaviour of adobe units and mortars were studied. Laboratory and *in situ* cyclic tests on full-scale adobe masonry walls were performed. Test results reveal the behaviour and structural fragilities of adobe elements.

1 Introduction

In the near past, earth was a very common construction material in Portugal. Adobe and rammed earth were used through years in almost all types of construction, having this utilization declined during the first half of 20th century, with the emergence of cement industry. Rammed earth was more applied in south and adobe in littoral centre, especially in Aveiro district [1,2]. Presently, according to information from the municipality, about 25% of the existing buildings in Aveiro city are made of adobe. It is estimated that this percentage rises to 40% when referred to the entire district. Adobe can be found in varied types of construction: rural and urban buildings, many of which are still inhabited, walls for the delimitation of properties, water wells, churches and warehouses (Fig. 1). An important number of the urban adobe buildings are of cultural, historical and architectural recognized value, belonging some of them to the "Art Nouveau" style.
The techniques adopted in the construction of adobe buildings in Aveiro district were based in the accumulated experience, transmitted from generation to generation, and did not concern the seismic safety. Rehabilitation and strengthening of existing adobe constructions have also been disregarded during decades. This constructed park is thus not properly reinforced to resist to seismic actions, suffering of various structural anomalies and deficiencies. Structural rehabilitation of the existing adobe constructions is demanded, and constitutes an urgent matter. It presents, however, relevant difficulties, essentially due to the lack of information concerning properties and characteristics of the mechanical behaviour of adobe masonry. Technical studies for the determination of these properties and characteristics are necessary. The mechanical characterization of adobe existing masonry constitutes a fundamental instrument in the support of rehabilitation and strengthening projects, and even in the support of the design of new adobe constructions [3].

2 Experimental work developed

2.1 Introduction

The mechanical characteristics of adobe units and mortar samples were investigated. Cylindrical adobe specimens cores were subjected to compression and splitting tests, and prismatic mortar specimens were subjected to compression tests. The structural non-linear response of adobe walls has also been investigated in a series of full-scale tests, in the laboratory and *in situ*, with constant vertical load combined with imposed horizontal cyclic displacements.

2.2 Mechanical characterization of adobe units and mortars

2.2.1 Simple compression and splitting tests on adobe specimens

For the experimental testing campaign, it was selected a set of adobe samples units representative of different existing adobe construction typologies. Samples were collected from eight houses and eight land dividing walls, from different locations.
Cylindrical cores, with diameters ranging between 60 and 95mm, were extracted from the collected adobe samples units. These cylindrical cores had a height of approximately two times the diameter.
A total of 101 cylindrical specimens, 51 proceeding from houses and 50 from land dividing walls, were submitted to mechanical tests: 83 specimens were submitted to compression; and 18 to splitting tests (Fig. 2).
The adobe specimens present significant compressive strength values, varying from 0.32 to 2.46MPa. For each construction analysed, the tensile strength corresponds to approximately 20% of the compressive strength. Results for the analysed adobe

samples reveal a clear tendency for samples with larger fractions of small dimension particles to present superior compressive and tensile strength values.
The detailed description of the mechanical characterization testing campaign and of the obtained results can be found in [4, 5].

2.2.2 Simple compression tests on mortar specimens

10 mortar samples (2 from plaster and 8 from joints) taken from 3 different houses were submitted to compression tests (Fig. 2).
The load applied by the compression testing machine was transmitted through two square steel plates, with 40mm side. It was obtained for the unconfined average strength: 1.68MPa (house 1); 1.07MPa (house 5); and, 0.45MPa (house 12).

2.3 Tests on full-scale adobe masonry walls

2.3.1 Introduction

It were conducted tests on adobe masonry wall specimens, one in laboratory and another *in situ* conditions (Fig. 3), to characterize the mechanical behaviour of this masonry when subjected to cyclic actions, as those induced by earthquakes.
The wall tested in laboratory was subjected, initially, to a non-destructive dynamic test, to estimate the natural frequencies in each direction. These measured frequencies help on the dynamic characterization of the adobe masonry wall, and also on the calibration of numerical models. In a second phase, it was conducted a destructive test imposing constant vertical load combined with in-plane horizontal cyclic forces.
The wall tested *in situ* was subjected to dynamic characterization tests, and to two horizontal cyclic mechanical tests, namely: an in-plane semi-destructive test and an out-of-plane destructive test.
The detailed description of the procedures and of the obtained results can be found in [6].

2.3.2 Laboratory test results

The wall tested in the laboratory was constructed with units taken from an existing construction and with a mortar having a composition similar to the one traditionally used. The boundary conditions at the base of the wall avoid lateral displacements and rotations.
The natural frequencies in the two horizontal directions (transversal and longitudinal) were measured with a seismograph. A frequency of 10.94Hz in the transversal direction was measured and, from it, an average modulus of elasticity of 316MPa was estimated. Subsequently, it was applied a vertical load of 2.86kN on the top of the wall, and in-plane horizontal forces were imposed, in cycles of increasing amplitude, till the collapse was reached. A maximum horizontal force of 3.2kN was applied. The failure mode was traduced by the opening of a horizontal crack at the base of the wall.

2.3.3 *In situ* tests results

The wall tested *in situ* conditions was firstly subjected to dynamic tests. A frequency of 2.20Hz in the transversal direction was measured and, from it, an average modulus of elasticity of 101MPa was estimated.
For the cyclic tests on the wall it was not applied an additional vertical load. Initially, in-plane horizontal cyclic forces were imposed, in cycles of increasing amplitude. In a second phase, out-of-plane horizontal forces were applied to the wall, in cycles of increasing amplitude, but without inversion of the force signal, till the collapse was reached. A maximum horizontal force of 10.7kN was applied in-plane. This force was not raised to a higher level in order to allow performing the out-of-plane test. A

maximum horizontal force of 0.69kN was applied out-of-plane. The failure mode observed is characterized by a rotation at the base, with damage spread through the wall height.

3 Work in Development

A group at the Civil Engineering Department from the University of Aveiro has been developing research work focused in the rehabilitation and strengthening of the adobe constructed park of Aveiro district. The following methodology is being followed: i) detailed survey of the existing constructions and of the commonest structural and non-structural pathologies; ii) material mechanical characterization; iii) structural characterization and evaluation of structural safety; iv) development of non-structural rehabilitation and structural strengthening solutions. Part of the work developed was presented in this paper.

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